Integrated Supercapacitors For Nano-Morphic Systems

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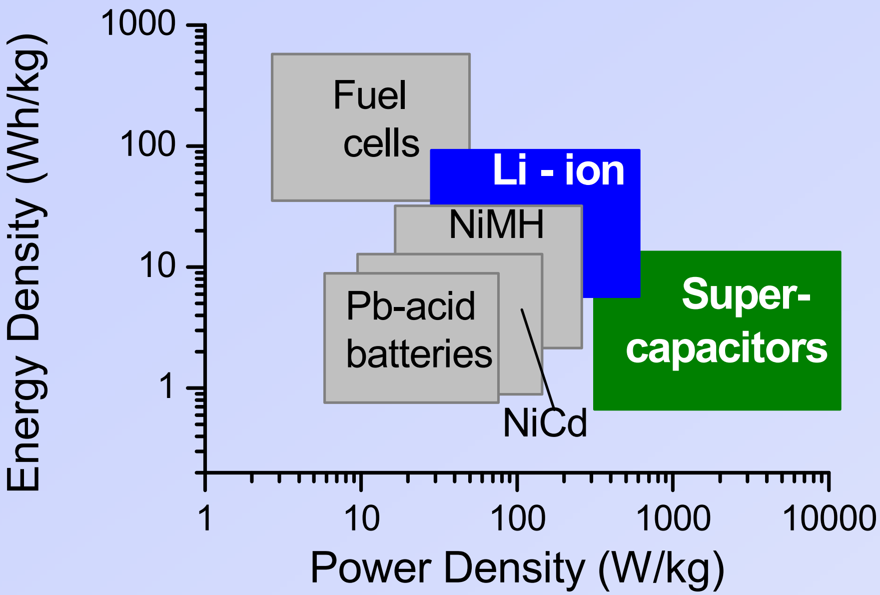
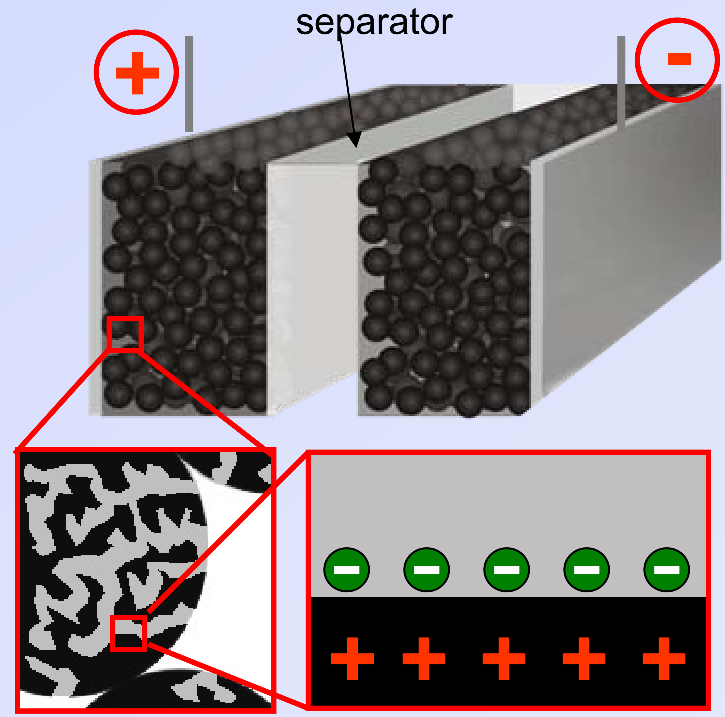
Supercapacitors





- **Charge storage:**
  - electrical double-layer (EDLC)
  - fast and reversible faradaic redox reaction (pseudocapacitance)
- **Energy storage depends on the ability of electrode to adsorb electrolyte ions under the applied potential**

Supercapacitors

Advantages over batteries:

- **Higher power**
- **Faster charging** (seconds vs. hours)
- **Less harmful** (no heavy metals)
- **Offer long cycle life** (>1,000,000 cycles vs. 500)
- **High efficiency** (> 95%)
- **Easy to detect the state of charge**
- **No fundamental limit for the voltage** (voltage only restricted by the decomposition of the electrolyte)

Supercapacitors

Why attractive for nano-morphic systems:

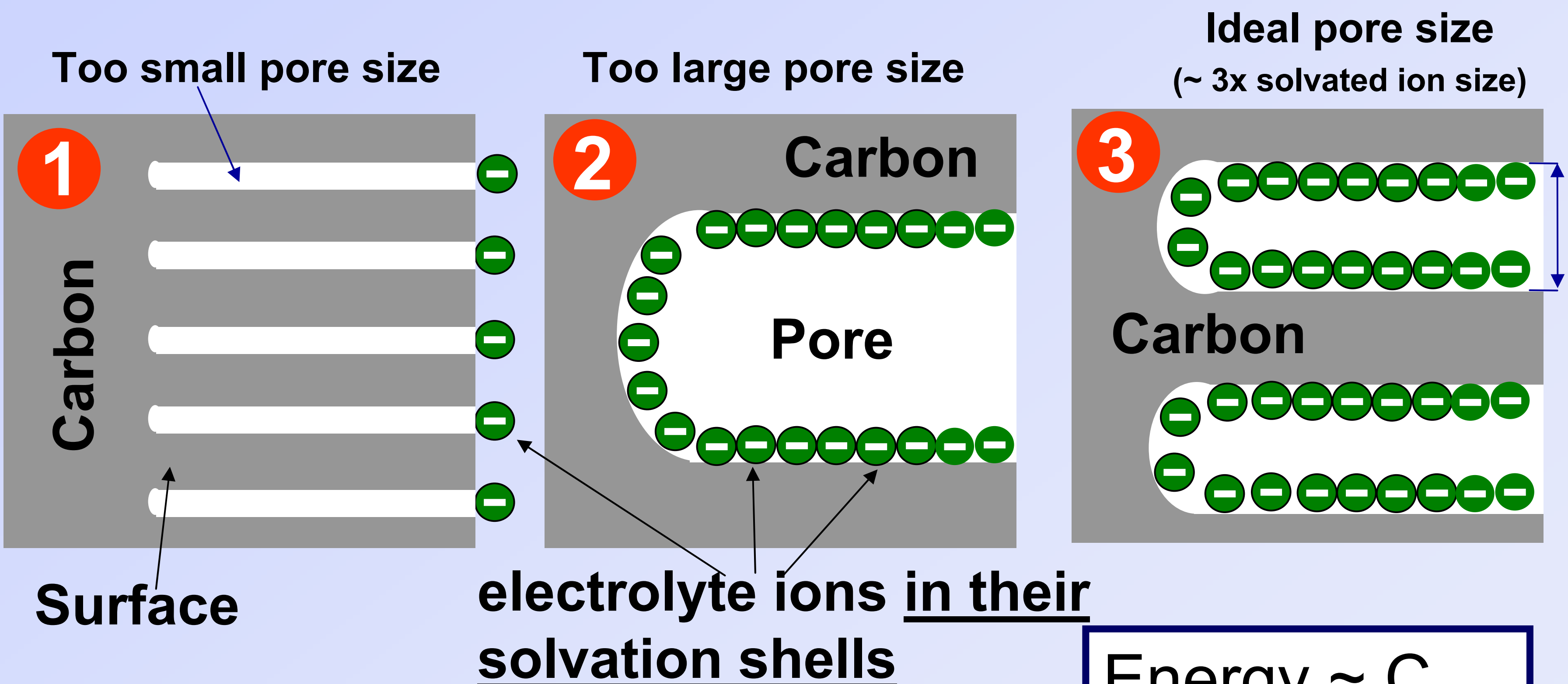
- **Provide peak power**
  - signal transmission
  - electroshock (e.g. destruction of cancer cells*; electro-therapy / cell stimulation)
  - activation (e.g. of bonding mechanism or release of drugs that come near the target cell, etc.)
- **Opportunity to control ion concentration in the proximity**
  - sensing
  - curing cells (e.g. by controlling injection of specific ions)
  - selective ion adsorption depending on the ion size possible
- **Simple construction / easy miniaturization and integration**
- **Long life** (could be longer than human life)
- **In combination with fuel cells will provide the highest energy and power density**

** - Kirson et al., Cancer Res. 64, 3288, 2004*

Supercapacitors

How to increase the energy storage?

By better understanding the storage mechanisms!



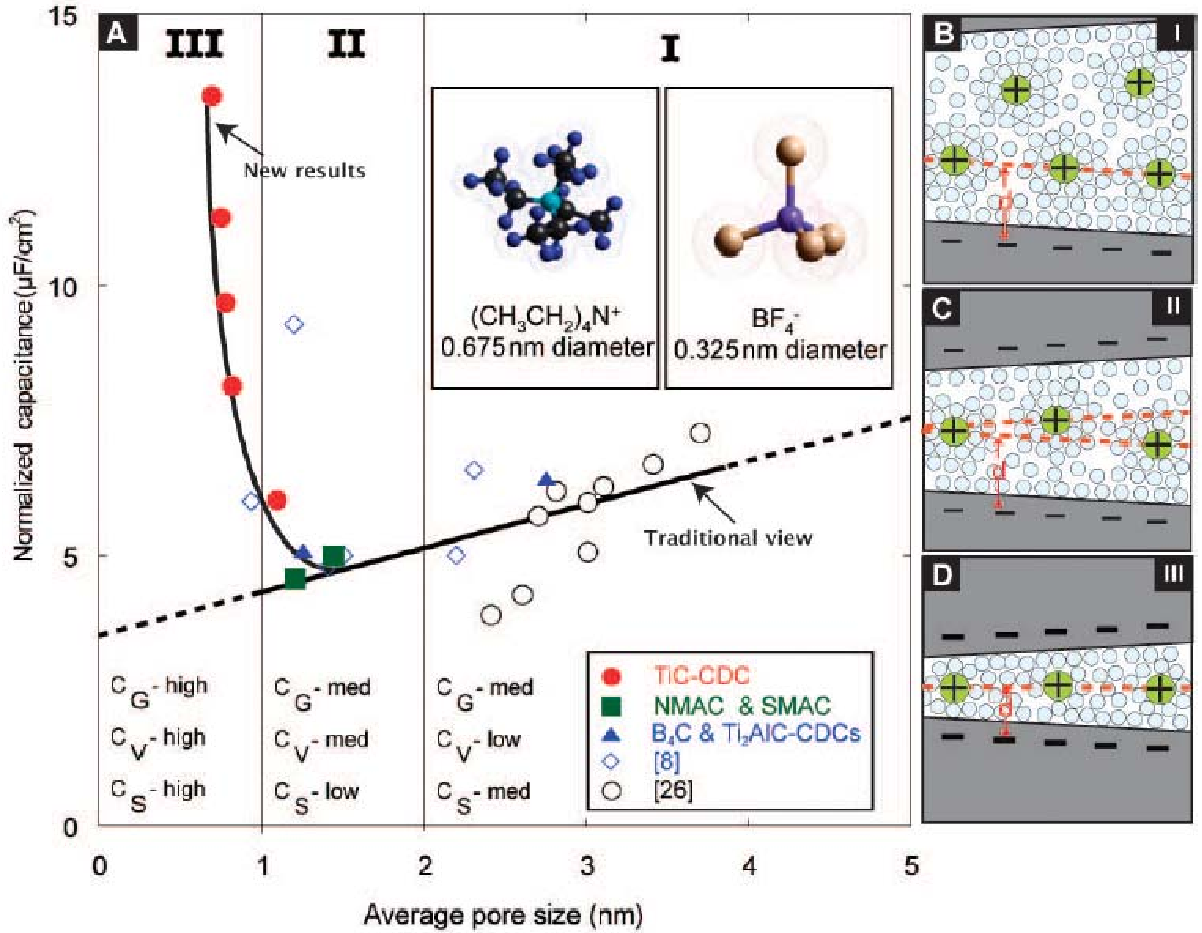
Traditional view

$$\text{Energy} \sim C$$

$$\text{Power} \sim \sqrt{C/R}$$

Supercapacitors

Energy storage in EDLC



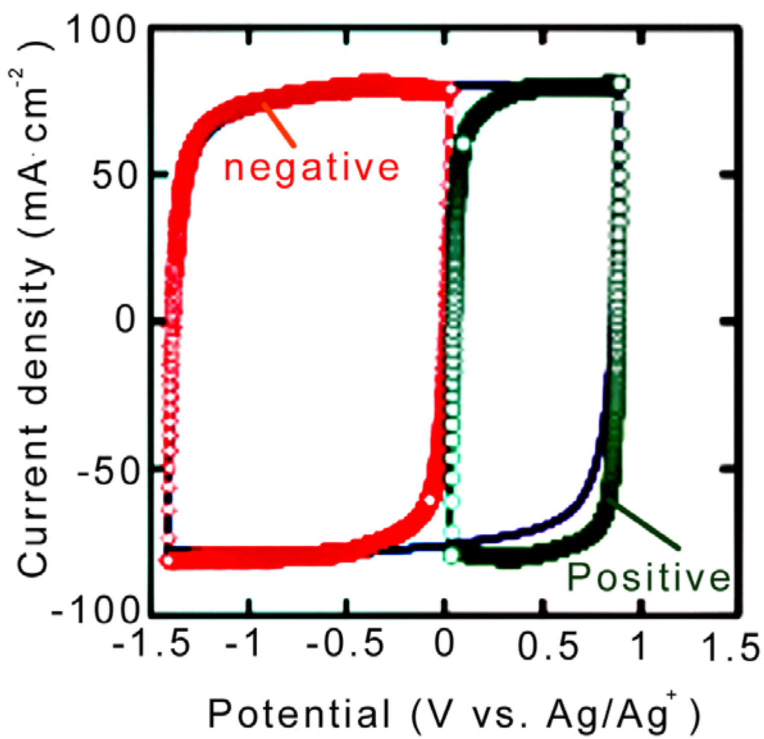
- *Distortion of solvation shells in sub-nm pores results in enhanced ion storage capacities*
- *C~1/d*

J. Chmiola, G. Yushin, Y. Gogotsi, et al., ***Science***, 313,1760-1763 (2006)

Supercapacitors

How to achieve selective ion adsorption?

By better controlling the pore size and microstructure!



Cyclic Voltammogram taken at a scan rate of 20 mV/s in 3 electrode cell configuration

- **Higher voltage drop on a negative electrode due to larger size of positive ions**
- **Difference in ions' size will affect their adsorption capacity if the pore size in electrode is tuned to dimensions of smaller ions**

Active material: C synthesized from TiC and having the pore size of about 0.72 nm

The size of anion – about 0.48 nm
The size of cation – about 0.67 nm

J. Chmiola, et al., ***Angewandte Chemi***, submitted (2007)

Supercapacitors

What are the fundamental limits of energy storage ?

1. Empirical estimation:

Energy in supercapacitor device $E \approx \frac{CV^2}{2} \cdot \frac{1}{8}$ ← *due to packaging, two C in a series etc.*

Capacitance: (a) 6-30 uF/cm^2 in carbon; (b) up to 200 uF/cm^2 in functionalized carbon;

(c) up to 200 uF/cm^2 in transition metal oxides

If surface area = 2000 m^2/g capacitance up to 4000 F/g could be reached

If max Voltage = 1V the Energy density ***E*** = 70 W·h/kg; if 3V, ***E***=630 W·h/kg

2. Semi-empirical estimation:

Assume formation of a close-packed monolayer of solvated ions (1e; d = 1.5 nm): 0.4 C/m^2

If could be achieved @ 1V: Capacitance = 4,000 uF/cm^2 and ***E*** = 1,400 W·h/kg

If could be achieved @ 10V: Capacitance = 400 uF/cm^2 and ***E*** = 14,000 W·h/kg

3. Fundamental limit:

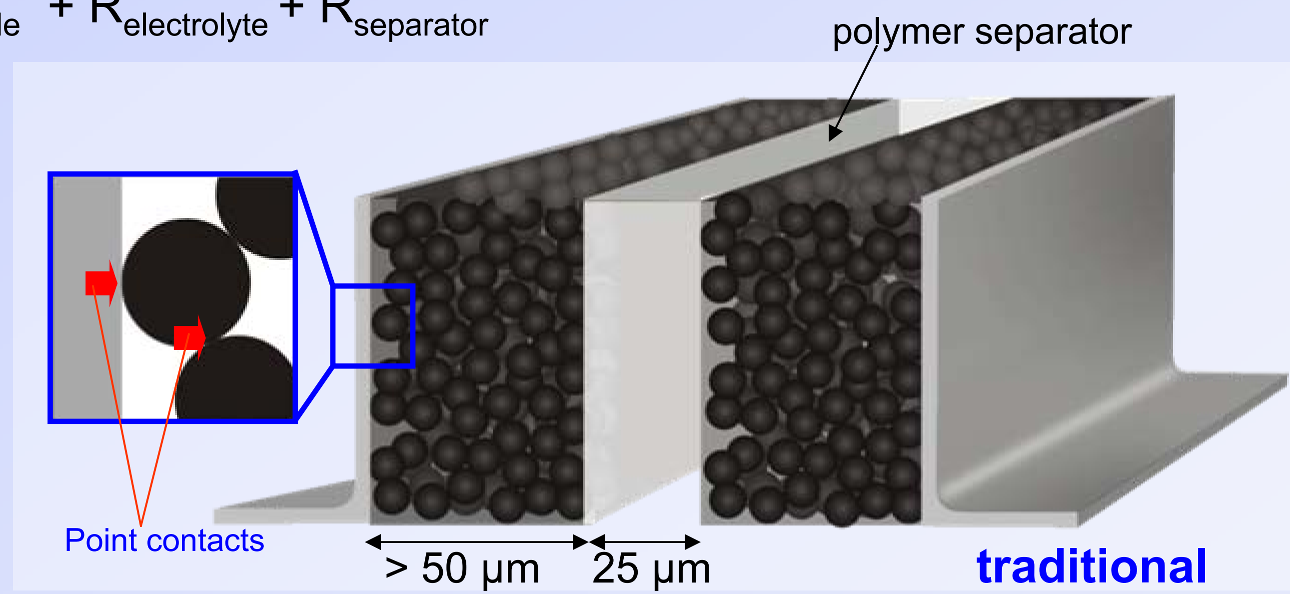
If 1e/atom in electrode: eNV/2 per electrode (1/2 of batteries **but** $V_{supercap}$ could be >2x higher)

Supercapacitors

Will micro-fabrication affect supercapacitor performance ?

• Power achievable is related to the Equivalent Series Resistance (ESR)

$$ESR = R_{cc/electrode} + R_{electrode} + R_{electrolyte} + R_{separator}$$

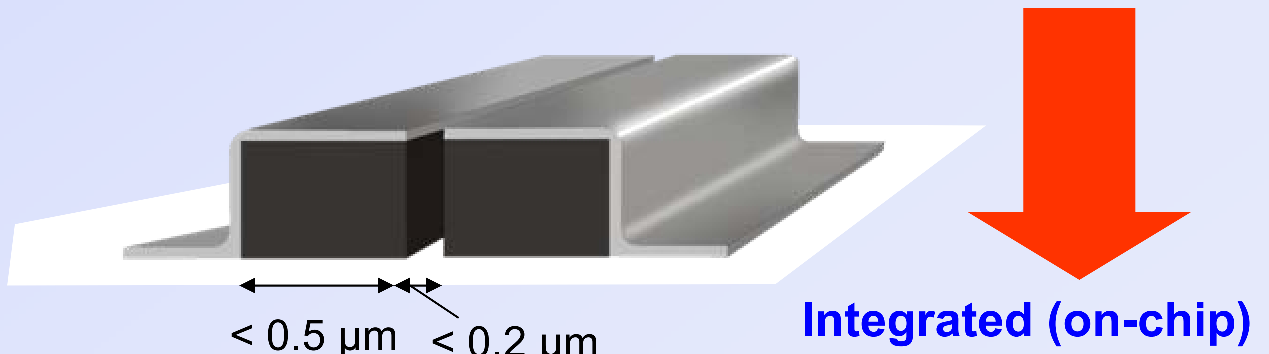


By moving from traditional to integrated supracapacitor we:

- decrease $R_{cc/electrode}$ by >100
- decrease $R_{electrode}$ by > 100
- decrease $R_{electrolyte}$ by > 100
- decrease $R_{separator}$ by > 100

Integrated supercap:

- > 10x $Power_{(gravimetric)}$
- > 20x $Power_{(volumetric)}$
- < 10% Charging time



Supercapacitors

- **Posses attractive properties** (higher power, faster charging, less harmful, very long cycle life, etc.)
- **High V might be possible** (voltage only restricted by the decomposition of the electrolyte)
- **Fundamentally do not have to exhibit low energy density** (state-of-the art performance might be limited by our poor understanding of ion propagation and adsorption mechanisms and by materials synthesis technologies)
- **Going to micro- and nano- scale should increase power density by over 10 times**
- **Capable to control concentration of selected ions in the vicinity of the cells**
- **Might not need hermetic sealing** (can use electrolyte of the extracellular matrix)